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Changes in Achilles tendon moment arm from rest to maximum isometric plantarflexion: *in vivo* observations in man

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1. The purpose of the present study was to examine the effect of a plantarflexor maximum voluntary contraction (MVC) on Achilles tendon moment arm length.

2. Sagittal magnetic resonance (MR) images of the right ankle were taken in six subjects both at rest and during a plantarflexor MVC in the supine position at a knee angle of 90 deg and at ankle angles of −30 deg (dorsiflexed direction), −15 deg, 0 deg (neutral ankle position), +15 deg (plantarflexed direction), +30 deg and +45 deg. A system of mechanical stops, support triangles and velcro straps was used to secure the subject in the above positions. Location of a moving centre of rotation was calculated for ankle rotations from −30 to 0 deg, −15 to +15 deg, 0 to +30 deg and +15 to +45 deg. All instant centres of rotation were calculated both at rest and during MVC. Achilles tendon moment arms were measured at ankle angles of −15, 0 , +15 and +30 deg.

3. At any given ankle angle, Achilles tendon moment arm length during MVC increased by 1–1·5 cm (22–27 %, $P < 0{\cdot}01$) compared with rest. This was attributed to a displacement of both Achilles tendon by 0·6–1·1 cm ($P < 0{\cdot}01$) and all instant centres of rotation by about 0·3 cm ($P < 0{\cdot}05$) away from their corresponding resting positions.

4. The findings of this study have important implications for estimating loads in the musculoskeletal system. Substantially unrealistic Achilles tendon forces and moments generated around the ankle joint during a plantarflexor MVC would be calculated using resting Achilles tendon moment arm measurements.

In musculoskeletal modelling applications accurate determination of moment arms is of crucial importance for estimating realistically either individual muscle forces or their effect. Traditionally, moment arms of different muscles have often been derived from dissected specimens, scaled to anthropometric characteristics and used for analysis of forces in the living musculoskeletal system (An *et al.* 1981; Burdett, 1982; Proctor & Paul, 1982). Alternatively, *in vivo* joint angle-specific measurements of moment arms have been taken in passive, resting muscles (e.g. Kawakami *et al.* 1994). However, it has been suggested that moment arms of active, contracting muscles may differ from those during a passive condition as measured in either *in vitro* cadaveric material or *in vivo* resting muscles (An *et al.* 1981; Spoor *et al.* 1990; Visser *et al.* 1990). *In vivo* changes in the Achilles tendon moment arm in response to changes in ankle position have been established by Rugg *et al.* (1990) using magnetic resonance imaging (MRI) and having the plantarflexors of the tested leg relatively contracted rather than passive. They postulated that Achilles tendon moment arm of a relatively active triceps surae might be increased compared with the resting condition at a given ankle angle. However, since measurements from passive muscles at rest were not taken, a verification of that hypothesis was not possible. Recent *in vivo* observations in our laboratory of an increased distance between aponeuroses in gastrocnemius lateralis and soleus by about 45 % during a maximum isometric voluntary plantarflexion compared with rest (Maganaris *et al.* 1998), implied an increased Achilles tendon moment arm during contraction of the triceps surae complex. An increased muscle thickness between aponeuroses during a plantarflexor MVC in two of the muscles of the triceps surae complex which are inserted into the Achilles tendon, could account for a displacement of the Achilles tendon action line away from its resting position. Moreover, joint reaction forces developed between the talus and adjacent bones during a plantarflexor MVC would alter the position of the talus affecting Achilles tendon moment arm length. Any change in the Achilles tendon moment arm between rest and a plantarflexor MVC would have important implications for both estimating the force transmitted through the Achilles tendon during a plantarflexor MVC and estimating the triceps surae moment generating capacity using musculoskeletal modelling. The purpose of the present study was to establish the magnitude and significance of any difference in the Achilles tendon moment arm in man between passive and maximally voluntarily contracted plantarflexors throughout the whole range of ankle motion.

METHODS

Subjects

Six healthy males, from whom informed consent had previously been obtained, volunteered to participate in this study. All were physically active and none had any subjective evidence of musculoskeletal injury or any orthopaedic abnormality in the lower extremities. Their average (mean $\pm$ S.D.) age, height and body mass were 28 ± 4 years, 175 ± 8 cm and 75 ± 7 kg, respectively. The study was approved by the Manchester Metropolitan University ethics committee.

Experimental protocol

Subjects performed MVC trials with the ankle plantarflexor group of the right leg, having the sole of the tested foot positioned against a mechanical stop vertically orientated in relation to the horizontal level (Fig. 1). Trials were carried out in the supine position at six

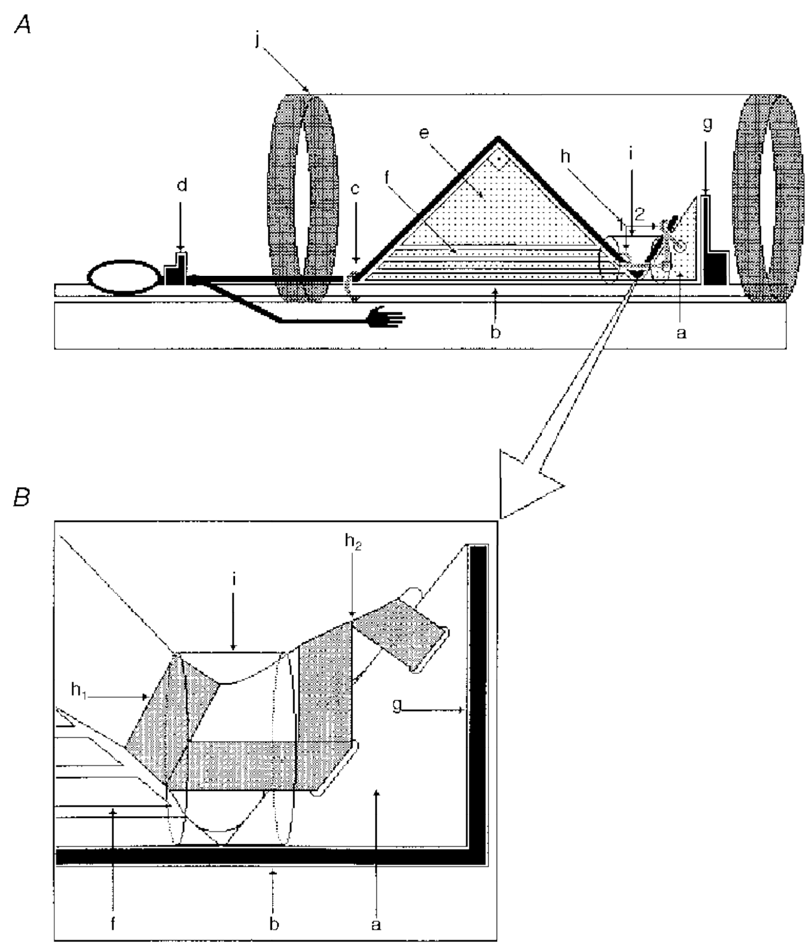

Figure 1. Diagram of the experimental set-up

A shows foot triangle block for positioning the ankle joint (a). The example shown is for an ankle angle of −15 deg where the oblique plane of the triangle on which the foot was placed formed an angle of 60 deg with the horizontal level. Horizontal board (b) for fixing mechanical stops (d) and (g). Velcro strap (c) at the level of hip joint and mechanical stops (d) for the upper body, knee isosceles triangle support (e) for positioning the lower leg at an angle of 45 deg relative to the horizontal level, boards (f) for adjusting the height of the knee triangle support (e), mechanical stop (g) for the tested foot, velcro strap (h) for fixating the heel (1) and the foot (2) on the foot block, anterior-neck surface coil (i) and MRI scanner (j). *B*, enlarged diagram of ankle and foot, with a, b, f, g and i as in *A*. Exact positioning of velcro straps for fixation of heel (h_1) and foot (h_2) are shown.

different ankle angles in the following order: −30 deg (dorsiflexed direction), −15 deg, 0 deg (neutral ankle position, the sole of the foot vertical to the tibia), +15 deg (plantarflexed direction), +30 deg and +45 deg. Alterations in the adopted ankle angle were achieved by means of triangular wooden blocks (six in total, each one cut according to the required ankle angle) on which the foot was mounted and secured with velcro straps. To prevent the heel rising away from the block, a velcro strap was placed on the anterior part of the lower leg right above the level of malleoli, crossed at the back and tied on the block in front of the heel. To ensure a stable position of the foot in the transverse plane, a second velcro strap was placed across and over the plantar surface of the foot and fastened onto the block (Fig. 1, enlarged representation of the foot). The knee of the tested foot was positioned at right angles on a triangular supporting frame. The mechanical stop for the foot and mechanical stops for the upper body placed at the level of the shoulders, were fixed on a horizontal board in an adjustable position according to the height of the subject. A velcro strap was placed over the hips and tied on the board to prevent the pelvis lifting away from the board. All trials were carried out with both limbs in a MRI 1·5 T/64 MHz scanner (G.E. Signa Advantage, Milwaukee, USA) with the ankle of the tested foot surrounded by an anterior-neck surface coil. Sagittal magnetic resonance (MR) images were taken at all ankle positions. At a given ankle angle, images were taken in two conditions; first at rest and afterwards during an MVC with the ankle plantarflexor group (Fig. 2). Subjects were instructed to develop an MVC in about 2 s pushing the ball of the foot against the block and to hold that contraction intensity for another 2 s. To make sure that the image was taken when plantarflexor contraction force had reached its maximum plateau value, scans were taken 2–3 s after the beginning of each trial. All MRI scans were taken using a Fast Multiplanar Gradient Recalled Acquisition in the Steady State (FMPGRASS) sequence at a flip angle of 90 deg. The variables used were: repetition time, 15 ms; echo time, 6·7 ms; field of view, 24 cm; number of excitations, 1·0; matrix, 256 × 128; slice thickness, 5 mm; and scanning time, 2 s. All sagittal scans were taken at the same level (based on axial pre-scanning at the level of malleoli).

Calculation of centres of rotation

In the present study rotation of the ankle joint from plantarflexion to dorsiflexion was treated as a planar mechanism (Sammarco *et al.* 1973; Siegler *et al.* 1988; Rugg *et al.* 1990). Ankle joint instant centres of rotation were located following the graphical approach described by Reuleaux (1875) for ankle angle rotations from −30 to 0 deg, from −15 to +15 deg, from 0 to +30 deg, and from +15 to +45 deg. Instant centres of rotation were calculated from images taken both at rest and MVC. In the present analysis the tibia was

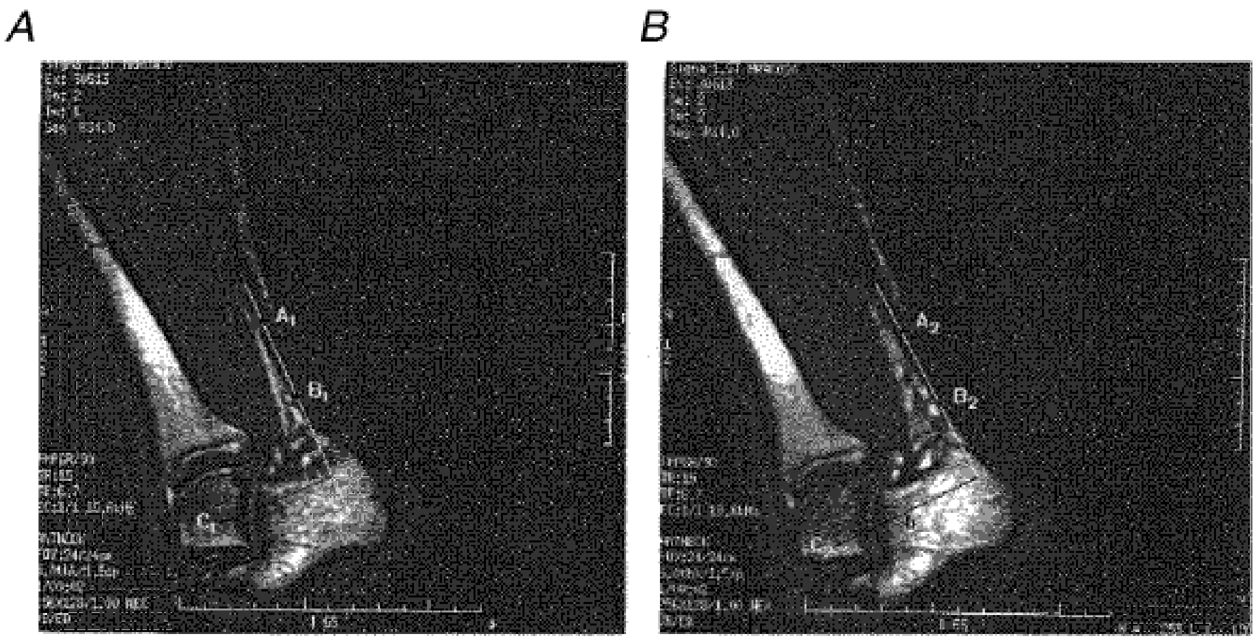

Figure 2. Sagittal MR images of the ankle joint

Sagittal MR images of the ankle joint at rest (*A*) and during an MVC with the ankle plantarflexors (*B*) at an ankle angle of +30 deg in one of the tested subjects. C_1 and C_2 are the instant centres of rotation calculated for an ankle rotation from +15 to +45 deg at rest (*A*) and during MVC (*B*), respectively. In each image the Achilles tendon is the black line next to the Kager's triangle (white triangular area). The straight white line drawn through the middle of the Achilles tendon represents the Achilles tendon action line. Points A_1 and B_1 in the image at rest and points A_2 and B_2 in the image during MVC are the markers whose horizontal position was measured in relation to a common reference point for assessing a displacement of the Achilles tendon in the transition from rest to MVC. Black lines a and b represent Achilles tendon moment arms at rest and during MVC, respectively. A displacement of the Achilles tendon in the transition from rest to MVC is indicated by an increase in the area that the Kager's triangle occupies during MVC compared with rest. The shift in the position of the instant centre of rotation in the transition from rest to MVC is also illustrated.

the stationary segment and the talus was considered to represent the whole rotating foot. In the image with the ankle angle at −30 deg at rest, two reference points were marked (Fig. 3). The first point (point A) was marked on the straight line passing from the posterior process of talus, vertically orientated in relation to the straight line connecting the lateral and the posterior processes of talus, 10 cm proximal to the posterior process. The second point (point B) was marked at a right angle 10 cm anterior to point A. Tracings were drawn on a transparency of the outline of the tibia and talus including the two reference points. The tibia outline on the transparency was superimposed on the tibia in the image showing the next ankle position at rest (0 deg) and the talus outline for this position was drawn in. The talus outline at this new ankle position was superimposed on the talus in the image at the initial ankle position (−30 deg) to mark the corresponding location of the reference points. Straight lines were drawn connecting each set of points and perpendicular bisectors to these lines were then identified. The point at which these bisectors intersected was taken as the instant centre of rotation for an ankle angle rotation from −30 to 0 deg. The same procedure was followed for all remaining ankle rotations at rest resulting in a calculation of a total of four instant centres of rotation. Identification of the four respective instant centres of rotation during MVC was performed on a different transparency. Differences for a given ankle rotation between rest and MVC were determined in a third transparency on which all eight centres of rotation (four centres at rest and four centres during MVC) were marked.

Movement of a given instant centre of rotation during MVC in relation to rest was measured in terms of co-ordinates in relation to a common reference point using a sonic digitizer (TDS, Blackburn, UK).

Achilles tendon moment arm measurements

In each image the Achilles tendon line of action was marked as a straight line along the centre of the tendon (Rugg *et al.* 1990). Achilles tendon moment arm was measured at ankle angles of −15, 0, +15 and +30 deg both at rest and during MVC by digitizing the perpendicular distance from the corresponding instant centre of rotation to the respective Achilles tendon line of action (for ankle angles of −15, 0, +15 and +30 deg centres of rotations derived from rotations from −30 to 0 deg, −15 to +15 deg, 0 to +30 deg and +15 to +45 deg, respectively) (Fig. 2).

Orientation of Achilles tendon

Determination of a change in the position of Achilles tendon between rest and MVC was carried out on the images at ankle angles of −15 deg, 0 deg, +15 deg and +30 deg. In each of the above images at a given ankle angle at rest, two points (A and B: 5 cm and 1·5 cm, respectively, from the attachment point of Achilles tendon on calcaneus) were marked along the straight line representing the action line of Achilles tendon, at the level of the Kager's triangle region (Fig. 2). Tracings were then made of the outline of the imaged part of the lower leg, foot, tibia, talus and the action line of Achilles tendon. Outlines of the lower leg, foot and tibia on the transparency were, respectively, superimposed on the image showing the ankle at the same position during MVC and the Achilles tendon line action position from this image was drawn in. Positions of the two reference points were then marked on the Achilles tendon action line during MVC. Differences in the horizontal position of the Achilles tendon markers were determined by digitizing their horizontal position in relation to a common external reference point.

Statistical treatment

Descriptive statistics for presented data included means and standard deviations. Differences in Achilles tendon moment arms between rest and MVC (two levels) and between different ankle angles (four levels) were tested using two-way analysis of variance. Simple effects tests were used to identify where interaction effects occurred. Tukey post hoc analysis was used to determine significant differences between mean values. Student t tests were used for comparisons in locations of a given centre of rotation and marked point on the Achilles tendon between rest and MVC. Statistical difference was set at a level of $P < 0.05$.

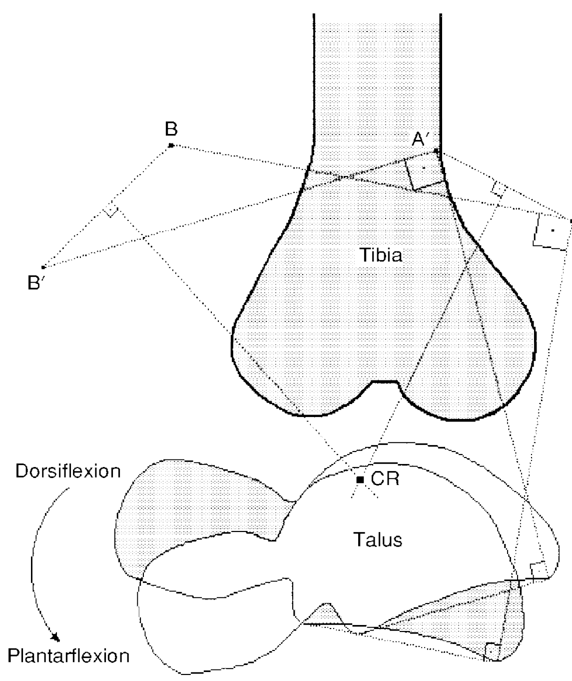

Figure 3. Representation of the graphical method (Reuleaux, 1875) used in the study for calculating instant centres of rotation

Talus represents the whole rotating segment in relation to which two reference points were marked. The intersection of the perpendicular bisectors to the lines connecting points A and A′ and points B and B′ was the instant centre of rotation for that given ankle rotation.

Table 1. Displacement of instant centres of rotation in the transition from rest to MVC

Centre of rotation	Derived from an ankle rotation (deg)		Horizontal direction (cm)	Vertical direction (cm)
	from	to		
1	−30	0	0·3 ± 0·2 *	0·4 ± 0·1 *
2	−15	+15	0·2 ± 0·1 *	0·4 ± 0·2 *
3	0	+30	0·3 ± 0·1 *	0·4 ± 0·2 *
4	+15	+45	0·3 ± 0·2 *	0·3 ± 0·1 *

Horizontal and vertical displacement (from the proximal to the distal region and from the dorsal to the plantar surface of the foot, respectively) of the position of each given instant centre of ankle rotation occurring in the transition from rest to MVC. Values are means ± S.D. ($n = 6$). * Significant difference ($P < 0{\cdot}05$) compared with the corresponding resting position.

RESULTS

Achilles tendon moment arm length

Achilles tendon moment arm increased as a function of ankle angle from the dorsiflexed to the plantarflexed direction both at rest and during MVC (Fig. 4). As ankle angle increased from −15 to +30 deg at rest, Achilles tendon moment arm increased from 4·4 cm to 5·5 cm (25%, $P < 0{\cdot}01$ but $P > 0{\cdot}05$ between +15 deg and +30 deg). During MVC, as ankle angle increased from −15 deg to +30 deg, Achilles tendon moment arm increased from 5·4 cm to 7 cm (30%, $P < 0{\cdot}01$). For any given ankle angle, Achilles tendon moment arm during a plantarflexor MVC increased by 1–1·5 cm compared with rest (22–27%, $P < 0{\cdot}01$). The difference in Achilles tendon moment between rest and MVC systematically increased from the dorsiflexed to the plantarflexed position.

Changes in spatial orientation between rest and MVC

Each one of the four instant centres of rotation moved during MVC compared with rest by 0·2–0·3 cm ($P < 0{\cdot}05$) horizontally from the proximal to the distal region and by 0·3–0·4 cm ($P < 0{\cdot}05$) vertically from the dorsal to the plantar surface of the foot (Table 1). At any given ankle angle during MVC, each one of the two Achilles tendon markers moved by 0·6–1·1 cm ($P < 0{\cdot}01$) in the horizontal direction compared with rest (Table 2).

Reproducibility of measurement

In one of the subjects the instant centre of rotation for an ankle rotation from 0 to +30 deg was calculated thirty times; fifteen times at rest and fifteen times during MVC. The locations of instant centres of rotation were measured in terms of co-ordinates in both horizontal and vertical directions in relation to an external reference point which was common for all measurements. The values for coefficient of variation for repeat measures at rest and during MVC were respectively 4·8 and 4·9% in the horizontal direction and 4·1 and 4·6% in the vertical direction. The latter variation in the location of that instant centre of rotation, resulted for a given orientation of the Achilles tendon in values for coefficient of variation of 5·1 and 4·7% in the Achilles tendon moment arm length at rest and during

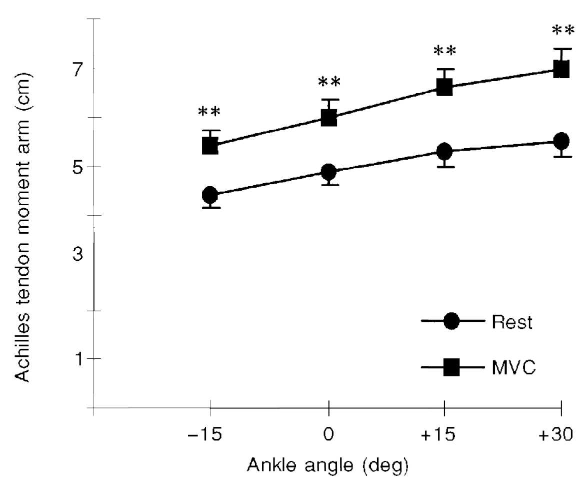

Figure 4. Changes in the Achilles tendon moment arm as a function of ankle angle at rest and during a plantarflexor MVC

Values are means ± S.D. ($n = 6$). ** Significant difference ($P < 0{\cdot}01$) between rest and MVC at any given ankle angle.

Table 2. Displacement of Achilles tendon markers in the transition from rest to MVC

Ankle angle (deg)	Marker A (cm)	Marker B (cm)
−15	1·1 ± 0·2**	0·6 ± 0·1**
0	0·9 ± 0·2**	0·6 ± 0·2**
+15	0·7 ± 0·2**	0·9 ± 0·1**
+30	0·6 ± 0·1**	1·1 ± 0·1**

Horizontal displacement in positions of Achilles tendon markers (markers A and B) occurring in the transition from rest to MVC at a given ankle angle. Values are means ± S.D. ($n = 6$). ** Significant difference ($P < 0{\cdot}01$) compared with the corresponding resting position.

MVC, respectively. In the same subject three images were taken during MVC at ankle angles of −15, 0 and +15 deg. The coefficient of variation for repeated digitizing of the Achilles tendon moment arm at an ankle angle of 0 deg was 7·9%.

DISCUSSION

The present findings verified our hypothesis of an increased Achilles tendon moment arm during a maximal voluntary contraction (MVC) with the ankle plantarflexor group compared with passive plantarflexors. In the present study, magnitudes of contraction forces exerted against the blocks were not measured. Consequently there was not a force reference value for confirming whether an image at a given ankle position was taken at a true maximal isometric contraction intensity (MVC). However our subjects, who were accustomed to performing maximum isometric plantarflexions, were instructed to perform with maximal effort in all contractions.

A limitation with *in vivo* morphometrics during high-intensity contractions is an artefact derived from any motion in the studied segment consequent upon tremor. Such motion can decrease resolution in the recorded image and this can result in unrealistic dimensions in the scanned structures (Spoor & Van Leeuwen, 1992). In the present study such an effect was minimized by restricting to 2 s both contraction and scanning times.

A change of orientation of a tendon during contraction of the respective muscle may occur in musculotendon units surrounded by retinaculum sheaths (e.g. ankle dorsiflexors). These fibrous structures retain the tendons of the respective muscles close to the joint and act as mechanical stops that deform during muscle contraction. Such a deformation is expected to result in an increased moment arm during contraction compared with rest at a given joint position (Rugg *et al.* 1990). Recently, using real time ultrasonography we observed in the subjects of the present study an increase in the distance between aponeuroses in gastrocnemius lateralis of about 0·7 cm (47%) and in soleus of about 0·6 cm (40%) during a plantarflexor MVC compared with rest at given ankle and knee positions (Maganaris *et al.* 1998; Fig. 5). By using the theoretical model presented in Fig. 6, we arrived at the hypothesis that an increase of about 1·3 cm (43%) in the whole thickness between the superficial aponeurosis of gastrocnemius lateralis and the deep

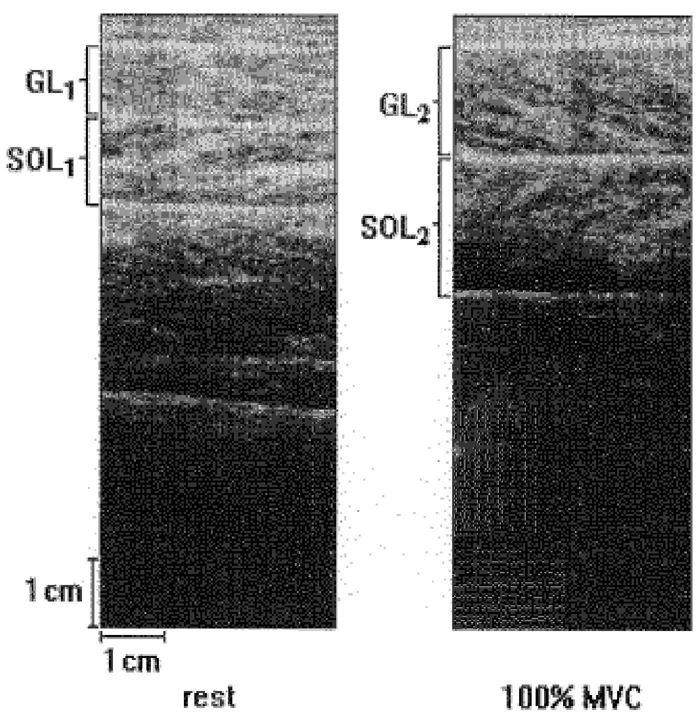

Figure 5. Sagittal sonographs of gastrocnemius lateralis and soleus muscles

Sagittal ultrasound images of gastrocnemius lateralis and soleus muscles at rest (GL$_1$ and Sol$_1$, respectively) and during a plantarflexor MVC (GL$_2$ and Sol$_2$, respectively). Presented sonographs were taken in the subject whose sagittal MRI scans at rest and during a plantarflexor MVC are presented in Fig. 4. Position of the subject is identical during ultrasound and MRI scanning (ankle and knee angles at +30 deg and 90 deg, respectively. The white horizontal stripes are echoes derived from the superficial and deep aponeuroses of each muscle and the oblique stripes are echoes derived from the fascia septas between the muscle fascicles. Notice the difference in muscle thickness (distance between superficial and deep aponeuroses) between rest and MVC in the scanned muscles.

aponeurosis of soleus (thickness of gastrocnemius lateralis + thickness of soleus) in the transition from rest to MVC should have an effect on the orientation of Achilles tendon at rest and consequently on the length of the resting Achilles tendon moment arm. By using morphometric MR image analysis we were able to confirm our initial hypothesis. Since there is no retinaculum or other mechanical constraint surrounding the Achilles tendon, it is reasonable to suggest a cause-and-effect relationship between an increased muscle thickness and a change in Achilles tendon orientation. However, it should be pointed out that data regarding the displacement of Achilles tendon in the present manuscript (Table 1) were collected using a fixation system for immobilizing mainly the ankle and the foot (Fig. 1). The safest way to fix the whole lower leg would be to secure both ankle and knee joints. Moreover, location of a strap around the ankle right above the malleoli may have acted as a mechanical stop restricting further translation of the Achilles tendon away from the talus during static plantarflexion. Thus, it may be the case that the displacement of Achilles tendon recorded during MVC under the present experimental conditions was somewhat underestimated compared with what would have been observed with a fixation system leaving the ankle free. The effect of using the ankle strap on the position of Achilles tendon at rest was tested on one subject at ankle angles of −15, 0, +15 and +30 deg. No differences were found in the orientation of Achilles tendon action line between a strapped and a strap-free ankle at any given ankle angle ($P > 0{\cdot}05$, Student's t tests for each of the points A and B).

Assuming a mean resting Achilles tendon length of 8 cm (Cummins *et al.* 1946; Weinreb 1994) and using the model presented in this study it was calculated that at the

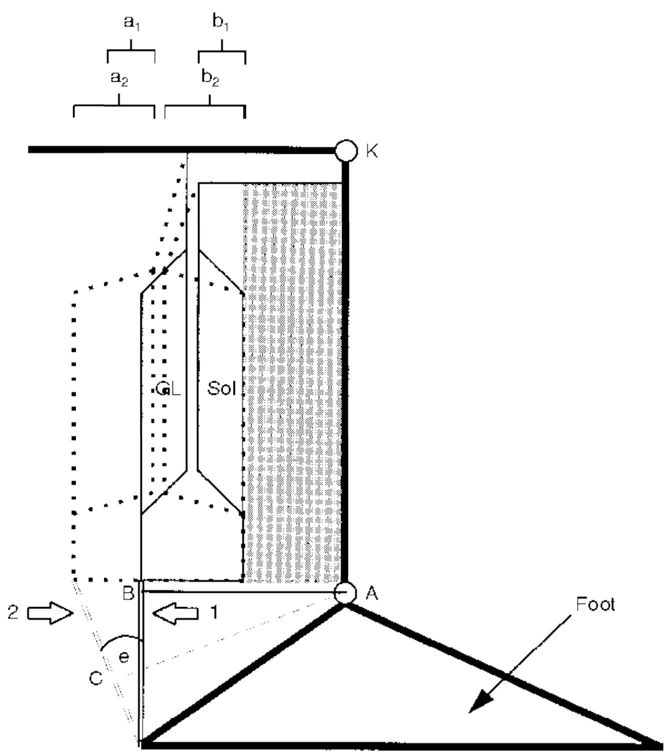

Figure 6. Biomechanical model of the lower extremity

Two-dimensional model of the lower extremity (lateral aspect of the right foot) at the reference ankle position representing the foot as a rigid body neglecting intertarsal, tarsometatarsal, metatarsophalangeal and interphalangeal joints. Continuous lines represent the positions of muscles at rest and dotted lines represent the positions of muscles during a plantarflexor MVC. K, knee joint; A, ankle joint; GL, gastrocnemius lateralis muscle; Sol, soleus muscle; a_1 and b_1, muscle thickness in gastrocnemius lateralis and soleus at rest, respectively; a_2 and b_2, muscle thickness in gastrocnemius lateralis and soleus during a plantarflexor MVC, respectively; 1 and 2, orientations of Achilles tendon at rest and during a plantarflexor MVC, respectively; e, angle between orientations of Achilles tendon at rest and during a plantarflexor MVC; (A–B) and (A–C), Achilles tendon moment arm lengths at rest and during a plantarflexor MVC, respectively. According to the present model, tissue behind the deep aponeurosis of soleus (grey area) does not deform in the transition from rest to MVC, as a result of an increase in the thickness in gastrocnemius lateralis and soleus. Such an assumption is based on an increased intramuscular pressure in adjoining co-contracting muscles (synergists, stabilizers or antagonists) during an agonists MVC in a segment where bones do not deform in response to changes in muscle shape.

neutral ankle position Achilles tendon during MVC should theoretically rotate in an anti-clockwise direction by an angle of about 10 deg in relation to the resting Achilles tendon around its attachment point to calcaneus (angle e in Fig. 6). Morphometrics revealed that at the neutral ankle position (0 deg), Achilles tendon during MVC rotated by 8 ± 2 deg according to the manner predicted by the model. Differences between actual Achilles tendon rotation angles and those predicted by the model in the transition from rest to MVC may be attributed to a deformation in the tissue lying behind the deep aponeurosis of soleus (grey area in Fig. 6). Moreover, the thickness of gastrocnemius medialis (the third muscle of the triceps surae complex) has been shown to remain constant during MVC compared with rest (Narici *et al.* 1996). The planimetric constraint of the model used does not allow incorporation of both gastrocnemii. Such a limitation may have contributed to the differences between actual Achilles tendon rotations and those predicted by the model.

Our findings regarding a change in the location of a given instant centre of ankle rotation between rest and MVC, are in line with those of Sammarco *et al.* (1973) concerning changes in location of a given instant centre of ankle rotation between non-weight bearing and weight bearing conditions. Although forces around the ankle joint differ between studies, the finding of a movement in a given instant centre of rotation when the ankle plantarflexor group contracts is consistent.

The present study showed that a resting Achilles tendon moment arm length should by multiplied by a factor ranging from 1·22 to 1·27 (from the dorsiflexed to the plantarflexed direction) to derive the respective value during a plantarflexor MVC. A difference in the Achilles tendon moment arm at given ankle and knee positions between rest and a plantarflexor MVC has important consequences for the analysis of forces acting on the musculoskeletal system. For example, an incorporation of the resting Achilles tendon moment arm at a given ankle angle in a moment equilibrium equation around the ankle joint during a plantarflexor MVC would lead to an overestimated force transmitted through the Achilles tendon compared with the force calculated incorporating the correct MVC moment arm value. This would, in turn, lead to an overestimation in the force produced in the direction of muscle fibres resulting in an overestimated specific tension in the triceps surae (that is force/physiological cross-sectional area). Using for example data by Fukunaga *et al.* (1996) and multiplying the Achilles tendon moment arm at an angle of 0 deg by a factor of 1·22, it can be calculated that the estimated force on Achilles tendon and specific tension of the triceps surae would have been about 18% (658 N and 2 N cm^{-2}, respectively) less than reported. Differences in the Achilles tendon moment arm between rest and MVC should also be taken into account in models simulating human triceps surae muscle performance (e.g. Woittiez *et al.* 1983; Out *et al.* 1996). Use of a resting Achilles tendon moment arm would result in an underestimation in both the triceps surae maximum moment–ankle angle and the whole ankle plantarflexor MVC–ankle angle relationships by between 18 and 21%.

In conclusion, the present study showed that Achilles tendon moment arms increase during an ankle plantarflexor MVC compared with measurements made at rest. Increases were attributed to a displacement of both Achilles tendon and centres of rotation away from their respective positions at rest and should be taken into account in the estimation of forces generated by muscles acting around the ankle joint.

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